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PHYSICAL–MECHANICAL PROPERTIES OF FIBERS MADE FROM SCORIA AND MATERIALS BASED ON THEM

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The physical–mechanical properties of mineral fibers manufactured from scoria obtained from two deposits in Armenia are studied. It is shown that the slag fibers can be used as an alternative to the widely used glass fibers. Their elastic modulus is identical to that of S-composition glass fibers and their strength is close to that of E-composition glass fibers. The elastic-strength properties of the composites exceed the corresponding indices of materials based on basaltic and andesite-dacite fibers.

Key words: mineral, glass fiber, composites, physical – mechanical properties.

Fibers manufactured from the widely occurring extrusive dacite volcanic rocks contain more than 50% silica, alumina, and oxides of iron and other elements and their materials base is practically infinite. It has been shown [1] that even under experimental conditions (no smoothly functioning production technology) andesite-dacite fibers exhibit high strength, exceeding that of E-composition glass fibers and comparable to that of basaltic fibers. The properties of the experimental samples of unidirectional composites based on them are close to the corresponding properties of fiberglass and basalt plastics.

The objective of our investigation is to continue the search begun in [1] for reinforcing fibers that can be an alternative to the widely used glass fibers. Mineral fibers made from scoria obtained from the Balaovit and Dalarik deposits in Armenia were investigated. In the process, the physical – mechanical and elastic – strength properties of elementary fibers and filaments as well as those of microplastics and composites based on them were studied.

The properties of fibers based on scoria from the Balaovit and Dalarik deposits are presented in Table 1. As compared with E-composition glasses, they have a higher content of oxides of iron and alkali metals, which compensate the effect of boron anhydride. The difference in the compositions of the rocks from the two deposits is manifested in the ratio of the oxides of silicon and alkali-earth metals — $SiO_2 : (CaO + MgO)$ equals 4.1 and 7.5, respectively, for rocks from the Balaovit and Dalarik scorias.

The fibers were produced in the temperature interval 1320 – 1360°C using 1.6 – 1.9 mm in diameter draw holes. The molten glass level was 4.9 – 5.1 mm. The fibers made from the Balaovit scoria were obtained under standard conditions (ShB-B) and with the “onion” cooled by an air stream (ShB-S). The pulling velocity of the fibers was 350 m/min. The fibers made from a melt of the rock from the Dalarik deposit was pulled at 350 m/min (ShDV-1) and 600 m/min (ShDV-2). The fiber diameter was 1.5 times shorter in this case. No finishing coats or lubricants were deposited on the surface of the fibers.

The strength, elongation, and elastic modulus of elementary fibers and filaments were measured for all experimental compositions, and the strength of microplastics and unidirectional composites obtained on the basis of the fibers and ÉDT-10 epoxy binder was also measured.

The tensile strength σ of the elementary fibers was measured using 10 mm long samples. A “Shopper” rupture test-

TABLE 1.

Fiber	Content, wt.%					
	SiO_2	Al_2O_3	B_2O_3	Fe_2O_3	CaO + MgO	$Na_2O + K_2O$
ShB	53.6	19.6	–	7.5	13.0	4.0
ShDV	60.3	17.2	–	7.1	8.0	4.6
E glass	54.0	14.5	10.0	0.3	20.5	< 1.0

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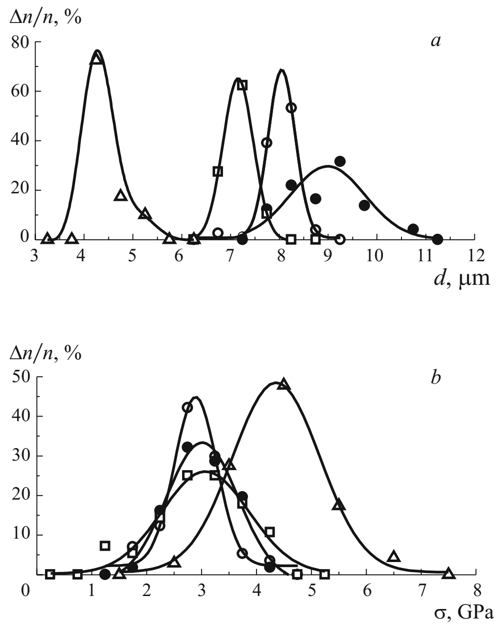

Fig. 1. Distribution curves for the diameters d (a) and strength under tension σ (b) of scoria fibers ShB-S (●), ShB-B (○), ShDV-1 (□), and ShDV-2 (△); Δn is the number of samples whose diameters and strength fall within the chosen range $\Delta d = 1$ μm or $\Delta\sigma = 1$ GPa; n is the total number of samples tested.

ing machine with maximum load 1 N was used to measure the rupture loads; at least 50 samples with each composition were tested. The samples for measuring the elastic modulus E were 50 mm long. The Instron 1122 tensile tester was used to test the latter samples. At least 20 – 30 samples were tested in each case. The stretching curves tensile stress σ – strain ε were obtained and used to determine the values of E.

Fibers with lineal density 400 tex and microplastics based on them were used for stretching on a 100 mm base. Before testing, cover pieces made of cardboard or glass cloth permeated with epoxy binder were glued on the ends of the samples to prevent the clamps from damaging the fibers.

TABLE 2.

Fiber	Number samples tested	d^*_{av}, μm	σ^*_{av}, GPa
ShB-B	57	7.9	2.8
ShB-S	56	8.9	3.1
ShDV-1	56	7.2	3.1
ShDV-2	69	4.5	4.4
A	60	5.7	3.2
Basalt	59	13.1	3.1
Glass:			
E	–	–	2.2 – 2.7
S	59	9.9	4.8

* The confidence intervals are ± 0.1 μm with respect to the diameter and ± 0.1 GPa with respect to the strength.

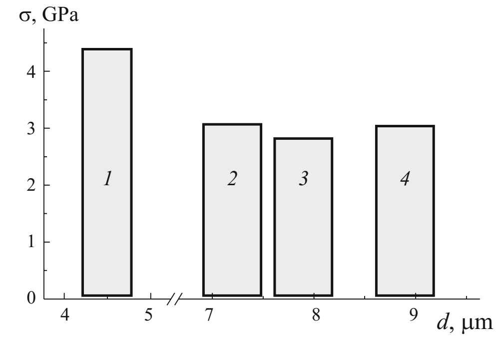

Fig. 2. Tensile strength of elementary fibers with the compositions ShDV-2 (*1*), ShDV-1 (*2*), ShB-B (*3*), and ShB-S (*4*).

Five-hundred millimeter long samples were prepared to determine the elastic modulus of the filaments. The Instron 1122 and Reinstein 250 rupture test machines were used for these tests.

To prepare microplastics segments of filaments with lineal density 400 tex were manually pulled through a feed-tension channel and secured on a special frame, which was placed inside a furnace at 160°C for 8 h to solidify the binder. Aside from microplastics, unidirectional plates 8 mm wide and 1.5 – 2.0 mm thick for compression and bending tests and 3 – 4 mm thick for shear tests were fabricated on the basis of mineral fibers to study the properties of the composites. In the process, plaits with lineal density 2000 tex were permeated with binder and placed in a collapsible metal mold in which solidification was conducted.

A three-point loading scheme was used to test the plates. Ordinarily, rupture occurs by a shear mechanism for l/h = 6 – 8 and by a bending mechanism for l/h = 20 – 30 or more, where l is the distance between the supports and h is the thickness of the sample. The well-known relations were used to calculate the elastic modulus and strength of the samples under bending σ_b and shear τ_{sh} [2].

For compression tests the samples were secured in flat centered clamps, keeping the testing base equal to approximately three times the thickness of the plate.

The results obtained were compared with the results for materials based on previously studied A andesite-dacite and E and S glass as well as B basalt fibers [1].

The distributions of the diameters and strength of the elementary fibers made from the scoria are shown in Fig. 1. Evidently, all distribution curves are unimodal and, apparently, correspond to the normal (Gaussian) distribution.

The properties of fibers on the standard base (10 mm) are presented in Table 2.

Diagrams characterizing the relation between the average diameter and the strength of elementary fibers made of scoria are presented in Fig. 2. The ShDV-2 fibers are much stronger than fibers with other compositions; this is due to their small diameter. However, on a 50 m base the strength of ShDV-2 fibers is virtually identical to that of ShDV-1 fibers.

The properties of elementary fibers on a 50 mm base are presented in Table 3.

The elastic modulus of scoria elementary fibers (90 GPa) is higher than that of andesite-dacite fibers and is identical to that of S-composition glass fibers; this is confirmed by the data presented in Fig. 3. The strength of andesite fibers is close to that of scoria fibers (1.9 – 2.6 GPa on a 50 mm base and 2.8 – 3.0 GPa on a 10 mm base).

Table 4 compares the strength of elementary fibers with the computed strengths of fibers made of different materials. The high strength of the elementary glass and scoria fibers is largely negated in microplastics and composite samples. The low strength of the fibers in filaments is conventionally attributed to their different lengths and to dynamical effects during rupture.

The elastic moduli of fibers are presented in Table 5. It follows from the data the high values of the elastic moduli of scoria elementary fibers in filaments, microplastics, and samples of composites decreased to the level for andesite fibers.

Table 6 presents the characteristics of composites in the form of 1.5 – 3.5 mm thick plates: volume content of fibers V_f; elastic modulus E_b and bending strength σ_b, compression strength σ_c, and shear strength τ_{sh}. The computed and measured values referenced to the same volume content of the fibers, specifically, $V_f = 60\%$, are presented together.

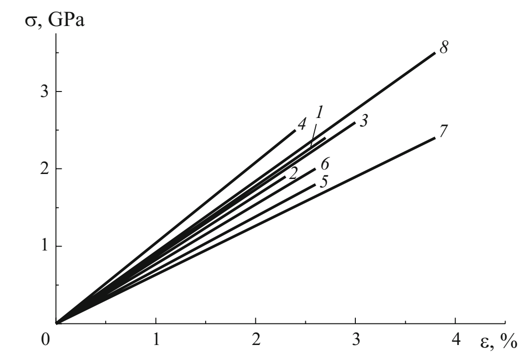

Fig. 3. Averaged $\sigma - \varepsilon$ diagrams of mineral fibers ShB-B (*1*), ShB-2 (*2*), ShDV-1 (*3*), ShDV-2 (*4*), A (*5*), basalt (*6*), E glass (*7*), and S glass (*8*).

The investigations have shown that in a number cases the composites based on scoria fibers possess higher elastic-strength characteristics than material made of andesite-dacite and basalt fibers.

In summary, scoria fibers can be regarded as a new form of reinforced continuous filler. These fibers are somewhat

TABLE 3.

Fiber*	n	E, GPa	ν_E, %	σ_{av}, GPa	ν_σ, %	ε, %	ν_ε, %
ShB-B	19	90.0	3.6	2.38	6.4	2.7	6.1
ShB-S	19	86.8	5.0	1.88	6.5	2.3	6.0
ShDV-1	25	88.8	11.2	2.62	5.6	3.0	5.3
ShDV-2	31	100.0	7.9	2.46	5.2	2.4	5.3
A	21	74.6	6.9	1.81	7.4	2.6	6.7
Basalt	20	80.4	5.7	2.00	6.4	2.6	6.5
Glass:							
E	–	72.0	–	–	–	–	–
S	20	95.0	2.9	3.52	3.7	3.8	4.1

* Fiber diameter — 4.5 – 14.0 μm; ν_E, ν_σ, and ν_ε — coefficients of variation.

TABLE 4.

Fiber	Fiber strength, GPa			
	in elementary samples (l = 10 mm)	in filaments (l = 100 mm)	in microplastics (l = 100 mm)	in composites
ShB-B	2.8	0.95	2.2	1.9
ShB-S	3.1	0.82	2.2	2.6
ShDV-1	3.1	1.01	2.6	2.6
ShDV-2	4.4	0.90	2.3	2.5
A	3.2	0.70	2.3	2.5
Basalt	3.1	0.89	2.3	2.8
Glass:				
E	2.2 – 2.7	0.9 – 1.0	2.5	–
S	4.8	1.1	3.0	2.7

TABLE 5.

Fiber	Elastic modulus of fibers, GPa			
	in elementary samples (l = 50 mm)	in filaments (l = 450 mm)	in microplastics (l = 100 mm)	in composites
ShB-B	90	61	78	102
ShB-S	87	61	77	111
ShDV-1	89	92	98	107
ShDV-2	100	65	66	69
A	75	69	63	67
Basalt	82	68	63	68
Glass:				
S	95	88	83	89
E	72	–	–	–

TABLE 6.

Fiber	V_f, %	E_b/E_{V60}, GPa	σ_b/σ_{V60}, GPa	σ_c/σ_{V60}, GPa	τ_{sh}, MPa
ShB-B	45	46.0/61.0	0.85/1.13	0.36/0.48	46
ShB-S	44	49.0/73.0	0.90/1.23	0.39/0.53	42
ShDV-1	46	49.0/64.0	1.20/1.57	0.38/0.50	55
ShDV-2	42	29.0/41.0	1.05/1.50	0.33/0.47	47
A	52	29.1/33.6	0.98/1.13	0.41/0.47	52
Basalt	49	29.4/40.8	1.34/1.64	0.40/0.49	54
Glass S	44	34.8/47.4	1.24/1.69	0.45/0.61	56

stronger than andesite fibers. The physical – mechanical characteristics of unidirectional epoxy composites based on scoria fibers are higher than those of basalt and andesite-dacite plastics.

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